NASA-MSC-G-R-66-8
Supplemental Report 5
Copy No. 268

[redacted]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEMINI PROGRAM MISSION REPORT

GEMINI IX-A

Issued as: Supplemental Report 5
To: GT-11 Post Flight Analysis Report
Gemini XI
MSC-G-R-66-8

By: Gemini XI Mission Evaluation Team
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

(NASA-TM-X-61632) GT-11 POST FLIGHT REPORT (NASA) 44 p

N79-76520

Unclas
00/19 11107

(CODE)
(CATEGORY) [redacted]
44 (PAGES)
TMX-61632 (NASA CR OR TMX OR AD NUMBER)
FF No. 602(A)

PREPARED BY: INTERNATIONAL BUSINESS MACHINES CORP.
FEDERAL SYSTEMS DIVISION
BETHESDA, MARYLAND

~~GROUP 4~~
~~Downgraded at 3-year intervals; declassified after 12 years~~

~~CLASSIFIED DOCUMENT~~ - TITLE UNCLASSIFIED

~~This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.~~

DISTRIBUTION AND REFERENCING

This paper is not suitable for general distribution or referencing. It may be referenced only in other working correspondence and documents by participating organizations.

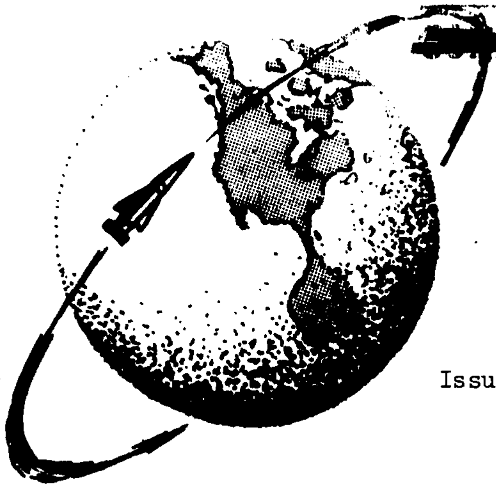
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS
December 16, 1966

COPY #268 [redacted] D/C 67-251-C

C67-86 85

CD# 75-100-0027
Copy 3

[redacted]



IBM

Federal Systems Division
Space Systems Center
Bethesda, Maryland

NASA-MSC-G-R-66-8
Supplemental Report 5

Issued as: Supplemental Report 5
To: GT XI Post Flight Analysis Report
Gemini XI
MSC-G-R-66-8
By: Gemini XI Mission Evaluation Team
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

GT-11 POST FLIGHT REPORT (U)

IBM NO: 66-M56-005

DATE: December 16, 1966

UNCLASSIFIED
CLASSIFICATION CHANGE
To ____
By authority of GDS-GP-4 Date 12/75
Changed by L. Shirley
Classified Document Master Control Station, NASA
Scientific and Technical Information Facility

~~[redacted] DOCUMENT CONTAINS INFORMATION [redacted] AFFECTING THE NATIONAL [redacted]ENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18 U.S.C., SECTIONS 793 AND 794, ITS TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO ANY UNAUTHORIZED PERSON IS PROHIBITED BY LAW.~~

~~**GROUP - 4**~~
~~**Downgraded at 3-year intervals; declassified after 12 years.**~~

ORIGINATED BY: T. L. Anthony
P. L. Beale
J. C. Condell
D. G. Ferneyhough

APPROVED BY: [signature]

APPROVED BY: [signature]
NASA GPO

[redacted]

955-3001-0

CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	CONCLUSIONS	2
2.1	Ascent	
2.2	Rendezvous	
2.3	Reentry	
3.0	ASCENT POST FLIGHT ANALYSIS	3
3.1	Insertion Conditions	
3.2	The Ascent Reconstruction	
3.2.1	Reconstruction Accuracy	
3.3	IVAR	
3.3.1	Flight Plan IVAR	
3.3.2	Actual IVAR Results	
3.3.3	Comparison of Techniques of Applying IVAR Corrections	
3.3.3.1	Method 1	
3.3.3.2	Method 2	
3.3.3.3	Method 3	
3.3.3.4	Relative Advantages and Disadvantages of Techniques	
3.3.3.4.1	In-plane Horizontal Correction	
3.3.3.4.2	Out-of-plane Correction	
3.3.3.4.3	Radial Correction	
4.0	RENDEZVOUS ANALYSIS	12
4.1	First Orbit Rendezvous	
4.1.1	Rendezvous Simulations	
4.1.2	Braking Analysis	
4.2	M = 1 (Direct Ascent) Rendezvous	
5.0	REENTRY ANALYSIS	33
5.1	General Analysis of Data	
5.2	Reentry Reconstruction	
5.2.1	Reconstruction Errors	
6.0	TELEMETRY TAPE PROCESSING	39

GT-11 POST-FLIGHT ANALYSIS

1.0 INTRODUCTION

This report documents the work done by IBM in the post-flight analysis of the GT-11 mission under NASA Contract No. NAS 9-6408. Following the completion of the GT-11 flight, a detailed analysis of the telemetry data from the Gemini on-board computer was carried out to determine, primarily, whether or not any abnormalities occurred in the operation of the IGS system during the flight. A secondary objective of the analysis was to correlate the data with the procedures of the mission and to explain, quantitatively and qualitatively the conditions which existed during the flight.

By agreement with the NASA GPO, the Analysis was carried out on only three mission phases: Ascent, Rendezvous and Reentry. The secondary objective of the analysis of each phase was not necessarily carried to its logical conclusion. To do so would have been a duplication of previous analyses and studies done on foregoing flights. If an aspect of the mission was indicated to be nominal and no abnormal behavior was lacking explanation, the analysis proceeded routinely to achieve the first and primary objective.

2.0 CONCLUSIONS

2.1 Ascent

Reconstruction of the GT-11 flight indicates that the GDC provided the proper IVAR corrections and that orbit corrections were performed in a manner that resulted in an orbit (86.6 by 150.6 n.m.) close to the targeted orbit (87 by 151 n.m.). If adjustment is made for errors in the IGS, it appears that the computer would have calculated a correction that would have resulted in a 86.6 by 150.9 n.m. orbit. Comparison of telemetry and tracking data also indicates that the IGS tracked the RGS with the degree of accuracy required to make a first orbit rendezvous possible.

2.2 Rendezvous

The performance of the IGS during the initial rendezvous sequence was acceptable. Only one orbital correction was necessary prior to TPI. The closed-loop solutions were used for TPI and the first midcourse correction. The closed-loop solution was not used for the second midcourse correction, but a satisfactory rendezvous would have resulted if it had been used.

TPF was accomplished by using line of sight and range rate braking alternately. Inertial line of sight rates did not exceed 0.104 deg/sec. throughout the portion of the TPF sequence investigated. Although the braking sequence was accomplished well within the budgeted fuel limits, it is felt that, in general, a more efficient braking sequence would result if line of sight braking were done initially and range rate braking were not begun until range to the target decreased to no more than half a mile.

Post flight simulations showed that from the standpoint of ΔV cost, relative trajectories, and inertial line of sight rates, a true M = 1 (first apogee) rendezvous would have been possible in the GT-11 flight even without the application of an IVAR maneuver.

2.3 Reentry

Examination of the flight data and the reconstruction of the flight revealed no anomalies in the reentry mission. The IGS performed well within the tolerances set by the design requirements. The flight data was reconstructed using the Gemini simulator to within 336 feet in position and 1.289 fps in velocity.

3.0 GT-11 ASCENT POST-FLIGHT ANALYSIS

3.1 Insertion Conditions

Table 3-3 shows the insertion conditions obtained in the flight as well as those derived from the Fortran and Operational Program reconstructions. Also shown are the total IGS errors and the flight values of the insertion conditions after they are adjusted for these errors. The values of the insertion conditions are within the range expected.

3.2 The Ascent Reconstruction

Ascent reconstruction was started shortly after SECO and continued until the computer was switched out of the ascent mode (342.5 to 473.6 seconds after liftoff). The FDI and IVI displays in this interval are shown in Table 3-1.

3.2.1 Reconstruction Accuracy

Table 3-2 shows a comparison of the position and velocity terms for the Fortran reconstruction, Operational program reconstruction and DAS data at three points in the flight. The Fortran reconstruction reproduced the DAS data to within 0.05 FPS and 29 feet for velocity and position respectively. The Operational Program reconstruction reproduced the DAS data to within 0.04 FPS in velocity and 29 feet in position. These results are within the ranges expected.

3.3 IVAR

3.3.1 Flight Plan IVAR

At SECO + 20 seconds, the IVI displayed 39, 11 and -4 for X, Y, and Z respectively. The attitude error signals at this time were pitch 17.7^{o}, yaw -5.6^{o} and roll 90.5^{o}. The flight plan called for the reading of addresses 85 and 94 to determine the radial thrust to be applied. Following this the vehicle was to be rolled upright, pitch zeroed on the FDI and yaw zeroed on the "8" ball.

After the proper attitude was reached, thrusting was to take place in the radial direction to produce a 5.1 FPS downward change in the radial velocity. Following this, a forward burn of 39.2 FPS was required to adjust apogee.

The forward burn would have raised apogee by 22.1 n.m. Since the initial orbit was 86.6 by 128.6 n.m., the resulting orbit would have been 86.6 by 150.7 n.m.

The radial burn would have decreased apogee altitude by 40 feet. This is considered insignificant. The major effect produced by a radial burn is to change the point in the orbit at which apogee occurs. For the burn considered, the rotation of the central angle of the orbit would have been 0.045° downrange, corresponding to a downrange displacement of 2.8 n.m. This would have caused apogee to occur 0.674 seconds later than it would have if no radial burn had been made.

The above discussion contains no correction for errors in the IGS system. After adjusting the position and velocity terms to compensate for the IGS errors, reconstruction shows that a radial burn of 4.4 FPS downward would have been calculated. As is shown by the above discussion, a radial burn of this magnitude would have no significant effect on apogee attitude but would rotate the line of apsidies.

With a correction for the IGS errors, reconstruction indicates that the computer would have calculated a horizontal burn of 39.54 FPS. If this burn had been made, apogee would have been raised by 22.3 n.m. This would have resulted in an 86.6 by 150.9 n.m. orbit.

3.3.2 Actual IVAR Results

Telemetry data indicate that the two IVAR burns were applied in reverse order to that called for in the GT-11 flight plan. At 360 seconds separation occurred. The roll upright maneuver was initiated at 368 seconds. At 380 seconds the spacecraft had assumed an upright attitude, and the proper pitch and yaw attitudes (-12.3° and 0° respectively) were achieved at 389 seconds.

Thrusting was initiated in the horizontal direction at 391 seconds. At 443 seconds the pitch FDI went full scale in the negative direction as the X IVI passed through zero, indicating the blunt end forward attitude as a slight overspeed was reached. At 446 seconds the X IVI drove to minus one where it remained until the computer was switched out of the Ascent mode.

At 451 seconds a radial burn commenced in the downward direction. This burn terminated at 466 seconds producing a ΔV of approximately -5 FPS.

The final orbit achieved after these burns was 86.6 by 150.6 n.m. In addition, the central angle of apogee was shifted downrange by .045° giving a downrange displacement of 2.8 n.m., and delaying apogee by 0.674 seconds.

These results are within the limits expected of the IVAR routine.

3.3.3 Comparisons of Techniques of Applying IVAR Corrections

In the recent Gemini missions, different techniques have been used to apply the IVAR corrections. In the following section, three of the techniques are discussed with regard to their relative advantages and disadvantages.

3.3.3.1 Method I

After separation read MDIU addresses 85 and 94, and through the use of previously prepared tables calculate the radial burn required. After zeroing pitch and roll on the FDI's and yaw on the "8" ball, commence thrusting to obtain the desired change in radial velocity. Next, commence thrusting in the FWD/AFT direction to zero the X IVI. This is the method called for in the GT-11 flight plan.

3.3.3.2 Method 2

The procedure for this method is the same as that for method 1 until the proper spacecraft attitude is achieved. At this point, thrusting is initiated to drive the FWD/AFT IVI to zero. Next, the necessary thrust is applied in the radial direction. This is the method actually used on the GT-11 flight.

3.3.3.3 Method 3

After separation the spacecraft is maneuvered to an attitude such that the pitch, roll and yaw FDI's are zeroed. At this point, thrusting is initiated to drive the FWD/AFT IVI to zero. This is the method that was originally proposed for the IVAR maneuver.

3.3.3.4 Relative Advantages and Disadvantages of the Techniques

In the following section the relative advantages and disadvantages of the techniques previously given are discussed in terms of their ability to correct for in-plane, out-of-plane, and radial errors.

3.3.3.4.1 In-plane Horizontal Correction

The in-plane horizontal correction obtained from each of the three methods given above will be essentially the same. This horizontal burn will affect the altitude of apogee but will make an insignificant change to the altitude of perigee. The in-plane horizontal burn is the most effective way of making the altitude correction for apogee.

3.3.3.4.2 Out-of-plane Correction

During IVAR, no correction is made for out-of-plane errors in methods 1 and 2. In method 3, the necessary thrust is made in the direction of the resultant of the in-plane and out-of-plane correction vectors. Thus, the one burn will correct both in-plane and out-of-plane errors. In the case of GT-11, the result of the out-of-plane correction would have been a shift in the angle of the orbit about the semi-major axis of 0.00036° to the south. This change is insignificant and is reasonable with the small out-of-plane error which occurred ($V_{\perp} = 0.15$ FPS). However, if the out-of-plane error is large enough to become significant, method 3 will provide the most efficient method of correction, assuming the IGS navigation errors are small. This is demonstrated by the fact that a 10 FPS out-of-plane correction coupled with a 30 FPS in-plane correction requires only 31.6 FPS if applied as a single vector.

3.3.3.4.3 Radial Correction

As the discussion above has shown, small changes in radial velocity at insertion have no significant effect on apogee altitude but do produce an appreciable rotation of the line of apsidies. Since apsidal location can be quite important in certain classes of rendezvous problems, method 3 must be considered to be at a disadvantage in that methods 1 and 2 both have provisions for correcting radial velocity errors at insertion while method 3 does not. A change in the program of the on-board computer would be required to include a radial component in the IVAR computations for use with method 3.

TABLE 3-1

TIME	$\lvert V\rvert X$	$\lvert V\rvert Y$	$\lvert V\rvert Z$	$\Delta\theta_b$	$\Delta\psi_b$	$\Delta\phi_b$
344.003	52.0	0.	0.	-0.	-0.	89.4
344.616	52.0	2.0	0.	-0.	-0.	89.4
345.260	52.0	2.0	-7.0	-0.	-0.	89.4
346.526	45.0	2.0	-7.0	-0.	-0.	89.5
347.843	45.0	5.0	-7.0	-0.	-0.	89.3
349.046	45.0	5.0	-8.0	-0.	-0.	89.1
350.331	41.0	5.0	-8.0	-0.	-0.	88.9
351.448	41.0	8.0	-8.0	0.	0.	88.7
352.685	41.0	8.0	-6.0	0.	0.	88.6
353.802	40.0	8.0	-6.0	0.	0.	88.5
355.036	40.0	10.0	-6.0	0.	0.	88.6
356.200	40.0	10.0	-5.0	0.	0.	88.8
357.485	39.0	10.0	-5.0	0.	0.	89.1
358.743	39.0	11.0	-5.0	0.	0.	89.5
360.066	39.0	11.0	-4.0	0.	0.	90.0
361.339	37.0	11.0	-4.0	17.7	-5.6	90.5
362.326	37.0	13.0	-4.0	19.4	-2.9	91.3
363.178	37.0	13.0	-1.0	20.9	-0.4	92.1
364.143	36.0	13.0	-1.0	21.8	1.1	92.4
364.955	36.0	15.0	-1.0	22.7	2.4	92.6
365.807	36.0	15.0	1.0	23.5	3.6	93.0
366.772	36.0	15.0	1.0	22.7	3.4	92.5
367.589	36.0	15.0	1.0	22.0	3.1	92.2
368.433	36.0	15.0	1.0	21.3	2.8	91.8
369.390	36.0	15.0	1.0	21.2	2.7	85.0
370.219	36.0	13.0	1.0	21.1	2.7	79.2
371.055	36.0	13.0	6.0	21.0	2.6	73.3
371.992	36.0	13.0	6.0	21.2	2.5	56.1
372.867	36.0	8.0	6.0	21.5	2.5	40.0
373.855	36.0	8.0	13.0	21.3	2.3	31.5
374.667	36.0	8.0	13.0	21.2	2.4	24.6
375.511	36.0	3.0	13.0	21.1	2.4	17.4
376.468	36.0	3.0	13.0	19.2	2.0	11.9
377.291	37.0	3.0	13.0	17.6	1.6	7.1
378.127	37.0	0.	13.0	16.0	1.2	2.3
379.060	37.0	0.	9.0	14.0	1.0	1.1
379.966	38.0	0.	9.0	12.1	0.7	-0.0
380.925	38.0	-1.0	9.0	11.6	0.8	-0.2
381.820	38.0	-1.0	8.0	11.1	0.9	-0.4
382.710	38.0	-1.0	8.0	10.7	0.8	-0.6
383.713	38.0	-1.0	8.0	8.6	0.7	-0.5
384.505	38.0	-1.0	5.0	7.0	0.5	-0.4
385.341	39.0	-1.0	5.0	5.3	0.2	-0.3
386.300	39.0	-1.0	5.0	2.9	0.9	-0.3
387.144	39.0	-1.0	1.0	0.8	1.4	-0.3
388.093	39.0	-1.0	1.0	0.6	1.5	-0.2
388.938	39.0	-1.0	1.0	0.3	1.5	-0.1
389.782	39.0	-1.0	0.	0.1	1.5	-0.1
390.739	38.0	-1.0	0.	0.1	1.6	0.
391.550	38.0	-1.0	0.	0.1	1.7	0.1
392.394	38.0	-1.0	0.	0.1	2.0	0.1
393.351	37.0	-1.0	0.	0.2	1.9	0.1
394.164	37.0	-1.0	0.	0.4	1.7	0.
395.000	37.0	-1.0	0.	0.5	1.4	-0.0
395.930	35.0	-1.0	0.	0.6	1.6	-0.2
396.774	35.0	-1.0	0.	0.6	1.9	-0.4
397.731	35.0	-1.0	0.	0.1	1.8	-0.4
398.546	33.0	-1.0	0.	-0.3	1.7	-0.4
399.390	33.0	-1.0	0.	-0.8	1.5	-0.4

TABLE 3-1 (continued)

TIME	$\lvert V \rvert X$	$\lvert V \rvert Y$	$\lvert V \rvert Z$	$\Delta\theta_b$	$\Delta\psi_b$	$\Delta\phi_b$
400.347	33.0	-1.0	0.	-0.6	2.2	-0.4
401.286	31.0	-1.0	0.	-0.4	2.8	-0.3
402.169	31.0	-2.0	0.	-0.2	3.6	-0.3
403.141	31.0	-2.0	0.	0.1	3.2	-0.4
403.985	29.0	-2.0	0.	0.2	2.8	-0.6
404.942	29.0	-1.0	0.	0.1	2.9	-0.6
405.755	29.0	-1.0	0.	0.0	2.9	-0.6
406.599	27.0	-1.0	0.	-0.1	2.8	-0.7
407.556	27.0	-2.0	0.	0.1	3.3	-0.6
408.370	27.0	-2.0	0.	0.2	3.7	-0.6
409.214	26.0	-2.0	0.	0.3	4.0	-0.5
410.171	26.0	-2.0	0.	0.4	3.6	-0.5
410.992	26.0	-2.0	0.	0.6	3.2	-0.5
411.828	24.0	-2.0	0.	0.7	2.5	-0.5
412.759	24.0	-1.0	0.	0.7	2.2	-0.4
413.603	24.0	-1.0	0.	0.7	1.9	-0.3
414.552	21.0	-1.0	0.	0.9	1.8	-0.2
415.379	21.0	-1.0	0.	1.0	1.8	-0.2
416.215	21.0	-1.0	0.	1.1	1.7	-0.2
417.164	19.0	-1.0	0.	1.0	1.5	-0.2
417.990	19.0	-0.	0.	0.8	1.3	-0.2
418.826	19.0	-0.	0.	0.6	1.0	-0.2
419.775	17.0	-0.	0.	0.2	0.6	-0.3
420.599	17.0	-0.	0.	-0.2	0.2	-0.3
421.556	17.0	-0.	0.	-0.0	1.3	-0.3
422.397	15.0	-0.	0.	0.1	2.3	-0.3
423.241	15.0	-1.0	0.	0.3	3.4	-0.3
424.198	15.0	-1.0	0.	0.3	3.2	-0.3
425.012	13.0	-1.0	0.	0.2	2.6	-0.3
425.856	13.0	-0.	0.	0.2	2.0	-0.3
426.813	13.0	-0.	0.	0.3	2.3	-0.1
427.629	11.0	-0.	0.	0.4	2.0	0.
428.465	11.0	-0.	0.	0.5	1.8	0.2
429.390	11.0	-0.	0.	0.4	2.4	0.1
430.234	9.0	-0.	0.	0.2	3.6	0.
431.191	9.0	-1.0	0.	0.3	4.7	-0.0
432.006	9.0	-1.0	0.	0.4	5.8	-0.1
432.850	7.0	-1.0	0.	0.4	6.3	-0.1
433.607	7.0	-1.0	0.	0.5	6.5	-0.2
434.625	7.0	-1.0	0.	0.4	6.7	-0.3
435.492	6.0	-1.0	0.	0.4	6.9	-0.3
436.472	6.0	-1.0	0.	0.1	8.3	-0.4
437.347	6.0	-1.0	0.	-0.1	8.9	-0.5
438.222	3.0	-1.0	0.	-0.4	10.2	-0.5
439.202	3.0	-1.0	0.	-0.2	14.0	-0.5
440.061	3.0	-1.0	0.	-0.1	18.2	-0.5
441.033	1.0	-1.0	0.	0.1	22.7	-0.4
441.877	1.0	-0.	0.	0.2	25.3	-0.4
442.721	1.0	-0.	0.	-179.7	36.1	-0.3
443.678	0.	-0.	0.	-179.5	20.2	-0.4
444.506	0.	-0.	0.	-179.4	15.9	-0.4
445.350	0.	-0.	0.	-179.3	9.0	-0.4
446.291	-1.0	-0.	0.	-179.1	13.4	-0.6
447.135	-1.0	-0.	0.	-179.0	24.9	-0.8
448.092	-1.0	-0.	0.	-178.9	26.5	-0.8
448.918	-1.0	-0.	0.	-178.8	27.3	-0.9
449.770	-1.0	-1.0	0.	-178.8	28.0	-1.0
450.735	-1.0	-1.0	0.	-178.8	30.1	-1.0
451.654	-1.0	-1.0	0.	-178.8	31.3	-1.0

TABLE 3-1 (continued)

TIME	$\lvert V \rvert X$	$\lvert V \rvert Y$	$\lvert V \rvert Z$	$\Delta\theta_b$	$\Delta\psi_b$	$\Delta\phi_b$
452.406	-1.0	-1.0	0.	-178.9	28.7	-1.0
453.371	-1.0	-1.0	0.	-179.0	30.0	-0.6
454.191	-1.0	-1.0	0.	-179.0	30.6	-0.3
455.035	-1.0	-1.0	0.	-179.1	26.3	0.0
455.977	-1.0	-1.0	0.	-179.0	27.3	0.2
456.821	-2.0	-1.0	0.	-178.9	23.8	0.4
457.778	-2.0	-1.0	0.	-178.9	27.4	0.5
458.611	-2.0	-1.0	0.	-179.0	31.5	0.6
459.455	-1.0	-1.0	0.	-179.0	37.5	0.7
460.412	-1.0	-1.0	0.	-178.9	43.2	0.8
461.267	-1.0	-1.0	0.	-178.9	49.1	0.9
462.111	-1.0	-1.0	0.	-178.9	54.5	1.0
463.048	-1.0	-1.0	0.	-179.1	54.0	1.2
463.900	-1.0	-1.0	0.	-179.3	47.9	1.4
464.865	-1.0	-1.0	0.	-179.4	49.2	1.5
465.688	-1.0	-1.0	0.	-179.4	47.1	1.6
466.531	-1.0	-1.0	0.	-179.5	43.3	1.7
467.489	-1.0	-1.0	0.	-179.6	45.0	1.8
468.320	-1.0	-1.0	0.	-179.7	46.5	1.9
469.164	-1.0	-1.0	0.	-179.8	43.9	2.0
470.121	-1.0	-1.0	0.	-179.9	45.6	2.1
470.947	-1.0	-1.0	0.	-179.9	45.0	2.1
471.791	-1.0	-1.0	0.	179.9	46.4	2.2
472.726	-1.0	-1.0	0.	179.8	48.5	2.2
473.578	-1.0	-2.0	0.	179.7	49.6	2.2

TABLE 3-2

Position and Velocity Comparisons

	V_x	V_y	V_z	X	Y	Z
FORTRAN	25 358.59	4130.07	-88.39	3436033	-21159881	-118813
OP PGM	25 358.59	4130.07	-88.39	3436033	-21159882	-118813
FLIGHT	25 358.59	4130.11	-88.39	3436060	-21159876	-118812
t = 344.003						
FORTRAN	25 281.29	4654.28	-84.08	3875047	-21089627	-120299
OP PGM	25 281.30	4654.29	-84.06	3875047	-21089630	-120299
FLIGHT	25 281.29	4654.32	-84.07	3875072	-21089656	-120296
t = 361.339						
FORTRAN	25 093.80	5587.08	-80.06	4657327	-20924684	-122850
OP PGM	25 093.83	5587.10	-80.03	4657330	-20924694	-122852
FLIGHT	25 093.82	5587.11	-80.04	4657332	-20924684	-122848
t = 392.394						

FORTRAN - FORTRAN Flight Reconstruction Results
OP PGM - Operational Program Flight Reconstruction Results
FLIGHT - DAS Flight Data

[redacted]

TABLE 3-3

IGS Injection Conditions

PARAMETER	FORTRAN[1]	OP PGM[1]	FLIGHT[2]	ERROR[3]	CORRECTED FLIGHT VALUE[4]
V_x	25 281.29	25 281.30	25 281.29	-2.1	25 283.39
V_y	4 654.28	4 654.29	4 654.32	+7.6	4 646.72
V_z	-84.08	-84.06	-84.07	+0.7	-84.77
X	3 875 047	3 875 047	3 875 072	+1395	3 873 677
Y	-21 089 627	-21 089 630	-21 089 656	-2179	-21 087 477
Z	-120 299	-120 299	-120 296	+529	-120 826
R	21 443 014	21 443 016	21 443 046		21 440 654
V_p	-8.428	-8.437	-8.444		-1.757
$V_\perp$	+0.161	+0.176	+0.166		-0.486
Γ	-0.0188°	-0.0188°	-0.0188°		-0.00392°
t_{SECO}			340.3		

(1) FORTRAN and Operational Program results were obtained from reconstruction of the flight using DAS accelerometer and gimbal angle data.
(2) IGS parameters listed were obtained from in-flight DAS data.
(3) IGS navigation errors obtained from TRW, error defined as IGS minus tracking data.
(4) IGS flight values corrected for navigation errors.

[redacted]

4.0 RENDEZVOUS ANALYSIS

4.1 First Orbit Rendezvous

The initial rendezvous of the GT-11 flight was accomplished during the first revolution. Following the IVAR maneuver only one orbital correction was made prior to TPI. This was a plane change maneuver of 3 ft/sec. to the north applied 29 minutes and 40 seconds after spacecraft lift-off.

Figure 4-I shows the time histories of the gimbal angles and radar parameters taken from computer telemetry words during the initial rendezvous sequence. The figure also contains a history of the values of total velocity change required to achieve rendezvous (ΔV_T) computed (1) in flight and (2) in a post-flight simulation using Best Estimated Trajectory (BET) target and spacecraft state vectors. The BET state vectors were obtained from TRW and are tabulated in Table 4-1.

As Figure 4-I shows, the pitch up maneuver to acquire the Agena target vehicle was conducted at approximately 26 minutes GET. Telemetry data show that the on-board computer was switched to the Rendezvous mode at 30:29 GET.

Radar samples to obtain relative position fixes for the Clohessy-Wiltshire equations were taken at the required times with no difficulty. Figure 4-II shows the relative trajectory reconstructed from the on-board radar data and the corresponding gimbal angles. As Figures 4-I and 4-II show, the radar data prior to TPI were relatively smooth and free of noise. Values of ΔV_T were obtained from the closed-loop system at the expected times. These values form a smooth curve which differs from the ΔV_T curve generated in post-flight simulations by no more than 2 ft/sec. at any point.

At 48:05 GET the START COMP button was depressed, and a closed-loop solution of 140.0 ft/sec. posigrade, 28.5 ft/sec. radially down and 5.0 ft/sec. north in navigational coordinates was computed. The spacecraft was oriented off boresight so that the entire TPI thrust vector could be applied with the aft firing thrusters. At 49:58 GET thrusting began. Telemetry data show that the velocity changes applied were 141.0 ft/sec. posigrade, 28.3 ft/sec. radially down and 4.7 ft/sec. north in navigational coordinates.

At 53:00 GET the spacecraft was pitched up to boresight attitude. Gathering of radar data for the closed-loop solution for the first midcourse correction began on time at 55:34 GET and proceeded normally. Once more the data were free of abnormal fluctuations. At 1:03:30 GET the final radar sample was taken, and the closed-loop system computed a correction of 2.0 ft/sec. retrograde, 2.9 ft/sec. radially upward and 4.0 ft/sec. south. Thrusting began at 1:03:42 GET, and velocity changes of 2.0 ft/sec. retrograde, 3.4 ft/sec. radially upward, and 3.9 ft/sec. south were applied.

Gathering of radar data for the closed-loop solution for the second midcourse correction began at 1:07:32 GET. During the data gathering period the values of range were well-behaved, but the angles were much noisier than at any previous point in the mission. The erratic behavior of the radar angles - particularly the azimuth angle - is apparent in Figure 4-I. This behavior produced the fluctuations in computed relative position seen in Figure 4-II. The final radar sample, taken at 1:15:25 GET, had an azimuth angle of -8.42^{o}, giving a lateral displacement of approximately 5300 ft. north. As Figure 4-II shows, this value is almost twice the lateral displacement which is estimated to have existed at that point in time. The resulting closed-loop solution for the second midcourse correction was 2.8 ft/sec. retrograde, 1.2 ft/sec. radially downward, and 10.9 ft/sec. south. At 1:15:44 GET velocity changes of 1.0 ft/sec. retrograde, 1.8 ft/sec. radially downward, and 0.4 ft/sec. south were applied.

4.1.1 Rendezvous Simulations

The BET target and spacecraft state vectors were used in conjunction with the IBM FORTRAN Module III simulator to produce a number of different post-flight simulations. These simulations provided a basis for comparing the results of applying the ground-computed, on-board computer-computed, and simulator-computed values of the rendezvous maneuvers with the results of the maneuvers actually applied in flight. Tables 4-2 and 4-3 show the maneuvers applied in these simulations in navigational and spacecraft coordinates respectively, and the resulting relative trajectories are shown in Figure 4-III. The run designations used in the tables and in the figure refer to the solutions used for each of the three rendezvous maneuvers (see the key in Figure 4-III).

For the in-plane components, Figure 4-III shows that the flight values, on-board computer values, and simulation values produced essentially the same trajectory. The close agreement between the run using the simulation values for the TPI and first midcourse maneuvers and those using the flight and on-board computer values for the maneuvers indicated that the in-plane components of the state vectors used closely represented the actual flight situation.

The trajectory obtained from the simulation using the ground-computed solution for TPI differed from the trajectories obtained from the other runs in both the in-plane and out-of-plane components. The radial component ($\Delta\dot{Y}$) of the ground TPI solution was 12 ft/sec. less than that of the on-board computer solution. The resulting trajectory rose too fast and required a 19 ft/sec. component radially downward to depress the trajectory and achieve a rendezvous.

The out-of-plane components of the simulated trajectories showed that the runs using the flight and on-board computer maneuver values had almost the same trajectory. The FFC trajectory differed noticeably at the end (as would be expected), but even so the results indicated acceptable performance of the on-board system. The GSS trajectory was nearly a mirror image of the flight trajectory. This was as expected because the out-of-plane component of the ground-computed TPI solution was of the same order of magnitude as the on-board computer solution but of the opposite sign. The SSS trajectory fell approximately mid-way between the FSS and GSS trajectories. This showed that, so far as the out-of-plane components are concerned, the problem defined by the state vectors used in these simulations was slightly different from either the problem solved by the on-board computer or the one solved by the ground complex.

It was not surprising that the ground complex TPI solution was incorrect. There was very little tracking data available prior to TPI. There was so little accurate tracking along the Eastern Test Range chain of stations that the ground complex was unable to compute a plane change maneuver in which it had any confidence for transmittal to the crew over Ascension Island. The plane change maneuver executed was applied after LOS at Ascension, and the ground-computed TPI solution was transmitted to the crew at Tananarive, the next station. This meant that the ground solution for TPI had to be computed from tracking data received prior to the plane change maneuver and a guess of what that maneuver would be.

The reasons for the differences between the on-board computer and simulator solutions were somewhat harder to assess. The trajectory of Figure 4-II placed the spacecraft north of the target moving southward toward a nodal crossing which would have occurred after TPI but before the desired time of rendezvous. The out-of-plane component of the on-board computer TPI solution was intended to move this nodal crossing downrange to the desired rendezvous point. On the other hand, the BET state vectors placed the spacecraft north of the target and moving northward at TPI, having passed through a nodal crossing shortly prior to TPI. The out-of-plane component of the simulator TPI solution was calculated to move the next nodal crossing uprange to occur at the proper time for a 120 degree rendezvous.

Because the backup TPI solution calculated by the crew agreed with the on-board computer solution, it was apparent from the radar and platform outputs that the spacecraft was following a trajectory such as that shown in Figure 4-III. No evidence of platform yaw misalignment or radar azimuth bias was noted during the investigation of this flight. Therefore, the most likely cause of the differences between the on-board computer and simulator solutions for the out-of-plane component of the TPI maneuver was inaccuracy of the BET state vectors.

4.1.2 Braking Analysis

It was decided that the errors in the BET state vectors, although small, were too large to permit an accurate analysis of the braking sequence. To circumvent this problem, an adjustment was made in the Agena state vector. (The adjusted state vector is tabulated in Table 4-4.) The adjusted Agena state vector and the BET spacecraft state vector were then used with a special simulation program developed during the analysis of the GT-10 flight. This program uses spacecraft accelerations, taken from on-board computer telemetry words, as inputs to an integration routine which propagates trajectories for both spacecraft and target, taking into account spacecraft thrusting. Time histories of some of the outputs of this simulation (elevation and azimuth turning rates of the inertial line of sight to the target, applied ΔV in navigational coordinates, radar range, and range rate) are presented in Figure 4-IV. The following comments are based on the figure.

At 1:16:04 GET, the computer was placed in the Catch-Up mode. The inertial line of sight rates at this time were 0.022 deg/sec. in elevation and 0.002 deg/sec. in azimuth. The rates grew slowly until at 1:17:41 GET they were 0.034 deg/sec. and -0.012 deg/sec. in elevation and azimuth respectively. At this point the START COMP button was depressed and thrusting began, marking the beginning of the braking or Terminal Phase Finalization (TPF) sequence.

During the first 40 seconds of thrusting velocity changes of approximately 2 ft/sec. posigrade, 3 ft/sec. radially upward, and 4 ft/sec. south were applied. These changes halted the negative trend of the azimuth rate and began driving the elevation rate toward zero. At 1:18:22, at a range of 8500 feet, the first range rate braking was applied, reducing the closing rate from 44 ft/sec. to 38 ft/sec. This thrusting, which was primarily radially upward and north, had no effect on the elevation rate but caused the azimuth rate to increase rapidly.

The trend of the thrusting done over the next minute was posigrade, down, and south. Although this thrusting effectively nulled the elevation rate, it had no effect on the azimuth rate, and it increased the closing rate 2 ft/sec. At a range of 5800 feet (1:19:33 GET) thrusting was applied up and north to reduce the closing rate from 40 ft/sec. to 25 ft/sec. This had no effect on the azimuth rate, which continued to increase, but it caused the elevation rate to increase rapidly.

Additional northward velocity changes halted the increase in azimuth rate at a peak value of 0.104 deg/sec., and retrograde thrusting begun at 1:20:44 GET began driving it toward zero. The increase in elevation rate was halted briefly, but an upward component of the thrust applied to control the azimuth rate drove the elevation rate to a peak value of 0.104 deg/sec. at 1:21:22 GET.

At 1:21:30 GET, at a range of 2700 feet, thrusting began retrograde, down, and north to reduce the closing rate. This thrusting continued until 1:23:01 GET when the simulation was terminated. During this interval, both azimuth and elevation rates moved through zero to negative values. The closing rate decreased to approximately 10 ft/sec. and range decreased to approximately 1000 feet. Since it was felt that, for ranges less than 1000 feet, range rate as well as inertial line of sight rates would be too sensitive to simulation errors to permit an accurate analysis, the simulation and analysis were terminated at this point.

The results of the simulation, as presented in Figure 4-IV, tend to support the following observations:

1.) Inertial line of sight rates as low as 0.03 deg/sec. can be detected and controlled effectively.

2.) Line of sight braking and range rate braking are basically incompatible. Range rate braking will usually undo efforts to control line of sight rates.

3.) Range rate braking has a much greater effect on line of sight rate control than vice versa.

IBM has analyzed the braking sequences in three flights: GT-6, GT-10 and GT-11. GT-6 was a flight in which no range rate braking was done until the range had closed to 2500 feet. In the GT-10 flight, range rate braking was begun at a range of 14,000 feet. Most of the braking in that flight was done to control range rate, and relatively little was done to control line of sight rates. For the GT-11 flight, line of sight braking and range rate braking were done alternately, with the first range rate braking applied at a range of 8500 feet. Of the three flights, GT-6 had by far the lowest fuel expenditure during braking.

The observations and facts presented above lead to the following recommendations for future rendezvous missions involving both line of sight and range rate braking:

1.) Confine initial braking maneuvers solely to control of line of sight rates.

2.) Commence braking to reduce range rate only when range to the target has been reduced to a half mile or less.

4.2 M = 1 (Direct Ascent) Rendezvous

The initial rendezvous of the GT-11 flight was popularly referred to as an "M = 1 rendezvous", but M = 1.5 would have been a better designation. The initial GT-11 rendezvous occurred after the spacecraft had traveled almost 360 orbital degrees from insertion. This was a major accomplishment. However, it raised the question of whether a true M = 1 or "direct ascent" rendezvous - rendezvous 180 orbital degrees after insertion - could have been accomplished.

To answer this question, IBM performed three M = 1 rendezvous simulations based on the GT-11 flight conditions. The Houston RTCC was asked to generate the targeted insertion conditions, based on the knowledge of the Agena 11 orbit that existed prior to GT-11 launch, that would have been used if GT-11 had been shooting for a true M = 1 rendezvous. The resulting state vectors for target and spacecraft are tabulated in Table 4-5. The large out-of-plane (Z) position and velocity of the Gemini relative to the Agena were caused by a restriction in the RTCC programs used to generate the state vectors. Since this restriction would have been eliminated had GT-11 been a true M = 1 rendezvous mission, targeted out-of-plane position and velocity were set to zero for the simulations.

Two sets of insertion errors (tabulated in Table 4-6) were subtracted from the targeted relative state vector to get the initial conditions for the simulations. The first set of errors represented the GT-11 insertion errors prior to the IVAR maneuver and thus gave a measure of the insertion accuracy of the Radio Guidance System. This set was used in the run designated RGS. The second set of errors, taken from after the IVAR maneuver, gave a measure of the insertion accuracy of the Inertial Guidance System and was used in the runs designated IGS and IGS/TPF.

For all three simulations the initial angle to rendezvous used was 90 degrees. Only one midcourse correction, 30 degrees from rendezvous, was applied in each run. TPI for the RGS and IGS runs was constrained to occur at a fuel minimum, and thus the elapsed time from insertion to rendezvous was not the same for both runs. For the IGS/TPF run, the time of TPI was picked to give a trajectory which would approach the target from below and ahead, with the spacecraft pitched up approximately 45° from the horizontal. The GT-11 crew could have selected the TPI time in the same way by monitoring the displays of estimated closing velocity ($\Delta\dot{X}_f$, $\Delta\dot{Y}_f$) available on the MDIU.

The thrust histories in both navigational and spacecraft coordinates as well as TPF estimates made at the point of minimum miss are tabulated in Table 4-7 for all three runs. The relative trajectories for the runs are shown in Figure 4-V. The azimuth and elevation rates of the inertial line of sight to the target for the IGS/TPF run are shown in Figure 4-VI. These data show that from the standpoint of ΔV cost, relative trajectories, and inertial line of sight rates, a true M = 1 rendezvous would have been possible in the GT-11 flight even without the application of an IVAR maneuver.

TABLE 4-1

FIRST ORBIT RENDEZVOUS BET STATE VECTORS

AGENA

GMT		12 September 14 hours 50 minutes 35.57 seconds
X	=	-.17256899E+8
Y	=	+.90935440E+7
Z	=	+.88984151E+7
$\dot{X}$	=	-.14134315E+5
$\dot{Y}$	=	-.20567536E+5
$\dot{Z}$	=	-.63319098E+4

SPACECRAFT

GMT		12 September 15 hours 12 minutes 14.54 seconds
X	=	-.12251511E+8
Y	=	-.17086807E+8
Z	=	-.51415361E+7
$\dot{X}$	=	+.20090274E+5
$\dot{Y}$	=	-.11444458E+5
$\dot{Z}$	=	-.10774880E+5

Cartesian co-ordinates

Aries reference frame

TABLE 4-2

THRUST HISTORY - NAVIGATIONAL COORDINATES

		FFF	FFS	FFC	FCS	FSS	GSS	CSS	SSS
TPI	$\Delta\dot{X}$	141.00	141.00	141.00	141.00	141.00	139.61	140.00	139.12
	$\Delta\dot{Y}$	28.29	28.29	28.29	28.29	28.29	16.95	28.50	28.61
	$\Delta\dot{Z}$	4.73	4.73	4.73	4.73	4.73	-6.60	4.95	-1.65
First	$\Delta\dot{X}$	-2.01	-2.01	-2.01	-2.02	-2.92	9.05	-2.72	-1.88
midcourse	$\Delta\dot{Y}$	-3.40	-3.40	-3.40	-2.94	-4.79	19.32	-6.92	-8.48
correction	$\Delta\dot{Z}$	-3.91	-3.91	-3.91	-3.98	-5.61	3.99	-5.79	-0.27
Second	$\Delta\dot{X}$	-0.96	-4.23	-2.77	-6.05	-0.36	1.12	-0.62	-0.67
midcourse	$\Delta\dot{Y}$	-1.74	-3.86	1.22	-6.16	-3.06	-3.81	-4.05	-3.76
correction	$\Delta\dot{Z}$	-0.41	-3.93	-10.88	-3.74	-0.13	0.05	-0.14	0.01
TPF	$\Delta\dot{X}_f$	-13.02	-14.89	-10.39	-16.76	-12.08	0.07	-12.95	-13.06
(Not actually	$\Delta\dot{Y}_f$	-35.36	-35.22	-31.02	-35.57	-35.95	-43.82	-36.47	-36.80
applied)	$\Delta\dot{Z}_f$	7.18	10.35	16.64	10.19	-7.41	-2.50	7.58	1.84
Miss distance, ft.		1626.8	72.5	3293.0	34.2	96.7	78.0	127.4	82.7

TABLE 4-3

THRUST HISTORY - SPACECRAFT COORDINATES

		FFF	FFS	FFC	FCS	FSS	GSS	CSS	SSS
TPI	ΔV_{X_b}	143.91	143.91	143.91	143.91	143.91	140.83	142.96	142.07
	ΔV_{Y_b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	ΔV_{Z_b}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
First	ΔV_{X_b}	1.34	1.34	1.34	1.02	1.83	-3.27	3.53	4.61
midcourse	ΔV_{Y_b}	3.79	3.79	3.79	3.90	5.46	-4.10	5.46	0.15
correction	ΔV_{Z_b}	-3.83	-3.83	-3.83	-3.51	-5.46	21.06	-6.81	-7.32
Second	ΔV_{X_b}	1.72	4.40	1.05	6.66	2.96	3.93	3.91	3.65
midcourse	ΔV_{Y_b}	0.00	2.97	-10.92	2.30	0.39	0.16	-0.55	0.17
correction	ΔV_{Z_b}	-1.07	-4.48	-0.69	-6.24	-0.77	-0.57	-1.10	-1.10
Total	ΔV_{X_b}	146.97	149.65	146.30	151.59	148.70	148.03	150.40	150.33
ΔV	ΔV_{Y_b}	3.79	6.76	14.71	6.20	5.85	4.26	6.01	0.32
applied	ΔV_{Z_b}	4.90	8.31	4.52	9.75	6.23	21.63	7.91	8.42
	$\Sigma \Delta V_b$	155.66	164.72	165.53	167.54	160.78	173.92	164.32	159.07

TABLE 4-4

FIRST ORBIT RENDEZVOUS ADJUSTED BET TARGET STATE VECTOR

GMT		12 September 14 hours 50 minutes 35.687 seconds
X	=	+.14200612E+8
Y	=	-.13227027E+8
Z	=	-.10097612E+8
$\dot{X}$	=	+.18419212E+5
$\dot{Y}$	=	+.17092654E+5
$\dot{Z}$	=	+.35759386E+4

Cartesian co-ordinates

Aries reference frame

TABLE 4-5

M = 1 RENDEZVOUS TARGETED INSERTION CONDITIONS

GMT 12 September 14 hours 44 minutes 14 seconds

AGENA (Cartesian ECIG)

X	=	-.14220497E+8
Y	=	+.12966462E+8
Z	=	+.10436566E+8
$\dot{X}$	=	-.17801210E+5
$\dot{Y}$	=	-.17969306E+5
$\dot{Z}$	=	-.18619193E+4

SPACECRAFT (Cartesian ECIG)

X	=	-.12970503E+8
Y	=	+.13610254E+8
Z	=	+.10319158E+8
$\dot{X}$	=	-.18937407E+5
$\dot{Y}$	=	-.17424180E+5
$\dot{Z}$	=	-.96832319E+3

SPACECRAFT RELATIVE TO AGENA (Target-centered curvilinear)

X	=	+.13526086E+7
Y	=	-.44569574E+6
*Z	=	+.18892124E+5
$\dot{X}$	=	-.92164014E+3
$\dot{Y}$	=	-.10322539E+3
*$\dot{Z}$	=	+.23997432E+3

* 0.0 used for simulations.

TABLE 4-6

M = 1 RENDEZVOUS INSERTION ERRORS

PRE-IVAR ERRORS (RGS)

X	=	0.0	ft.
Y	=	1281.0	ft.
Z	=	- 375.0	ft.
$\dot{X}$	=	40.58	ft. /sec.
$\dot{Y}$	=	7.65	ft. /sec.
$\dot{Z}$	=	- 0.147	ft. /sec.

POST-IVAR ERRORS (IGS)

X	=	300.0	ft.
Y	=	1200.0	ft.
Z	=	- 375.0	ft.
$\dot{X}$	=	2.0	ft. /sec.
$\dot{Y}$	=	4.0	ft. /sec.
$\dot{Z}$	=	- 1.0	ft. /sec.

Target-centered curvilinear co-ordinates

Simulation Value = Targeted Value - Error

TABLE 4-7

M = 1 RENDEZVOUS THRUST HISTORIES

		RGS		IGS		IGS/TPF	
		Navigational Coordinates	Spacecraft Coordinates	Navigational Coordinates	Spacecraft Coordinates	Navigational Coordinates	Spacecraft Coordinates
TPI	GMT	15:05:32		15:19:27		15:01:47	
	ΔV_x	- 11.4	103.4	18.0	19.5	- 6.3	79.9
	ΔV_y	102.8	0.0	- 7.6	0.0	- 79.6	0.0
	ΔV_z	0.5	0.1	- 0.9	0.0	1.1	0.2
Midcourse	GMT	15:21:48		15:34:48		15:17:48	
	ΔV_x	11.6	- 15.7	7.4	- 4.8	13.7	- 31.4
	ΔV_y	12.6	- 0.6	8.0	0.8	29.5	- 0.3
	ΔV_z	0.3	6.8	- 0.8	- 9.7	0.6	8.6
TPF	GMT	15:29:09		15:42:14		15:25:08	
	Min. Range	202.9	ft.	265.5	ft.	1162.3	ft.
	$\Delta \dot{X}_f$	- 98.94		-111.65		- 127.10	
	$\Delta \dot{Y}_f$	- 76.24		103.30		- 138.20	
	$\Delta \dot{Z}_f$	- 3.03		- 1.14		- 1.80	
	ΔV_f	124.94		152.11		187.77	

UNCLASSIFIED

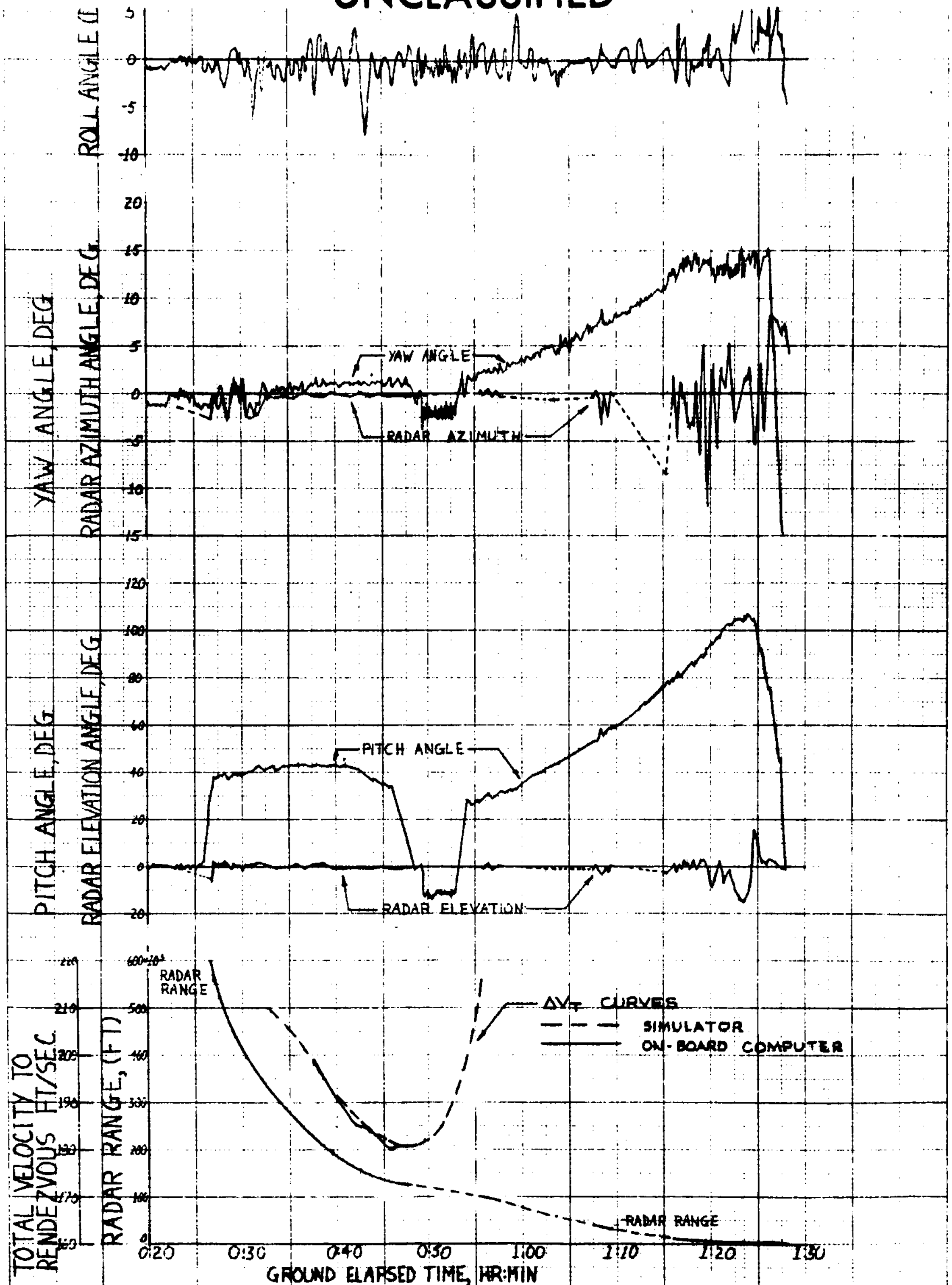


FIGURE 4-1 FIRST ORBIT RENDEZVOUS RADAR, GIMBAL ANGLE, ΔV_T TIME HISTORIES

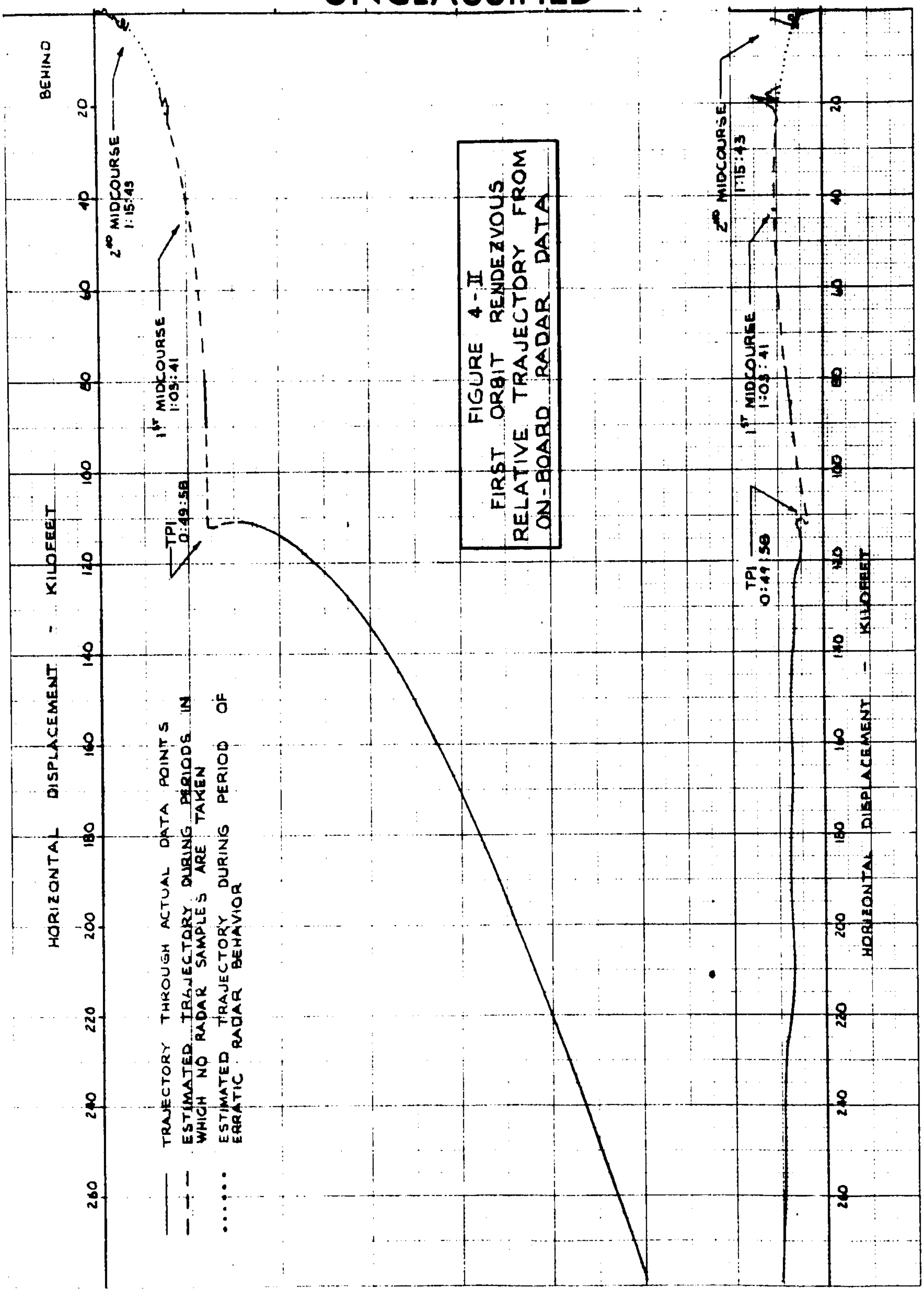


FIGURE 4-II
FIRST ORBIT RENDEZVOUS
RELATIVE TRAJECTORY FROM
ON-BOARD RADAR DATA

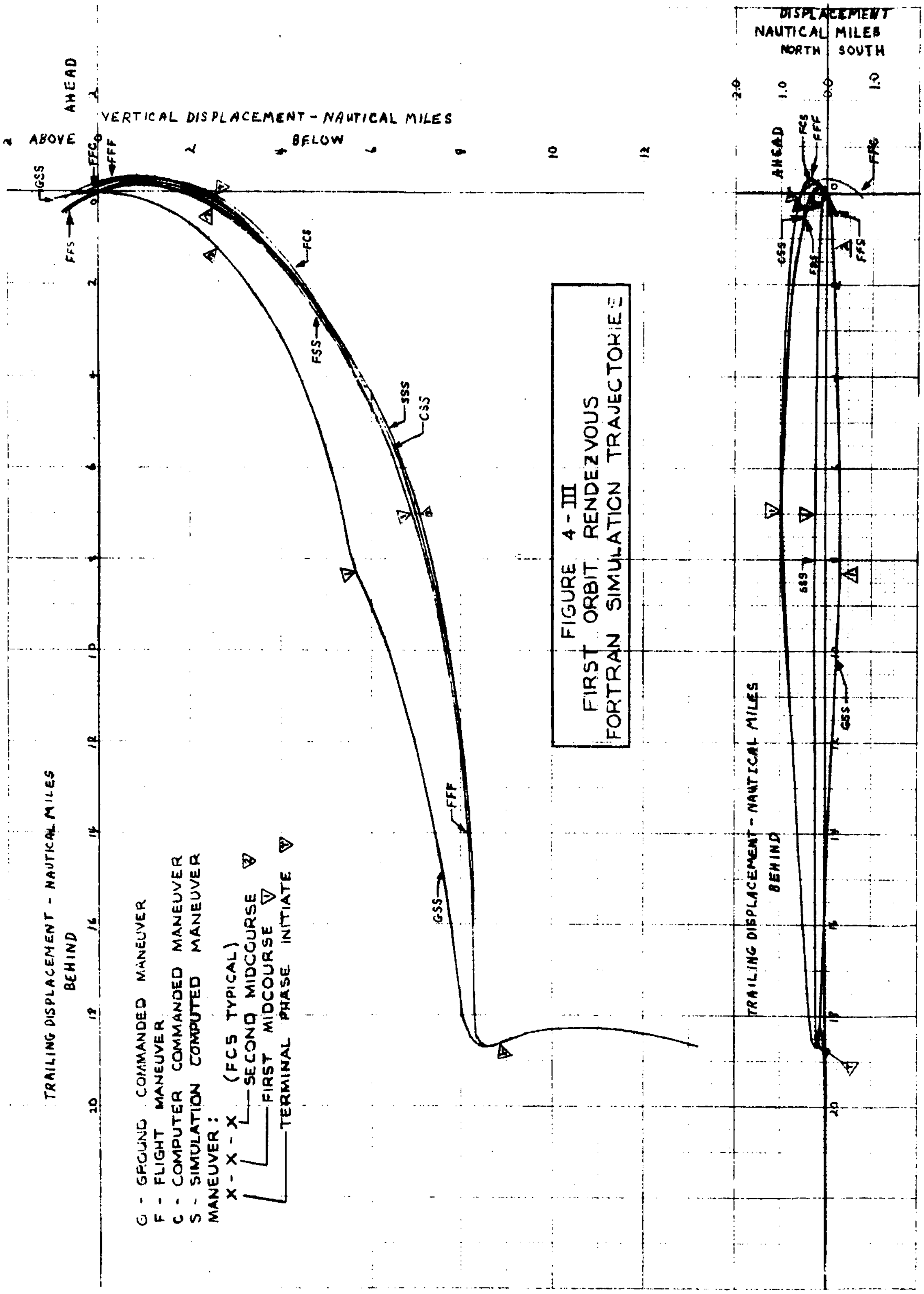


FIGURE 4 - III
FIRST ORBIT RENDEZVOUS
FORTRAN SIMULATION TRAJECTORIES

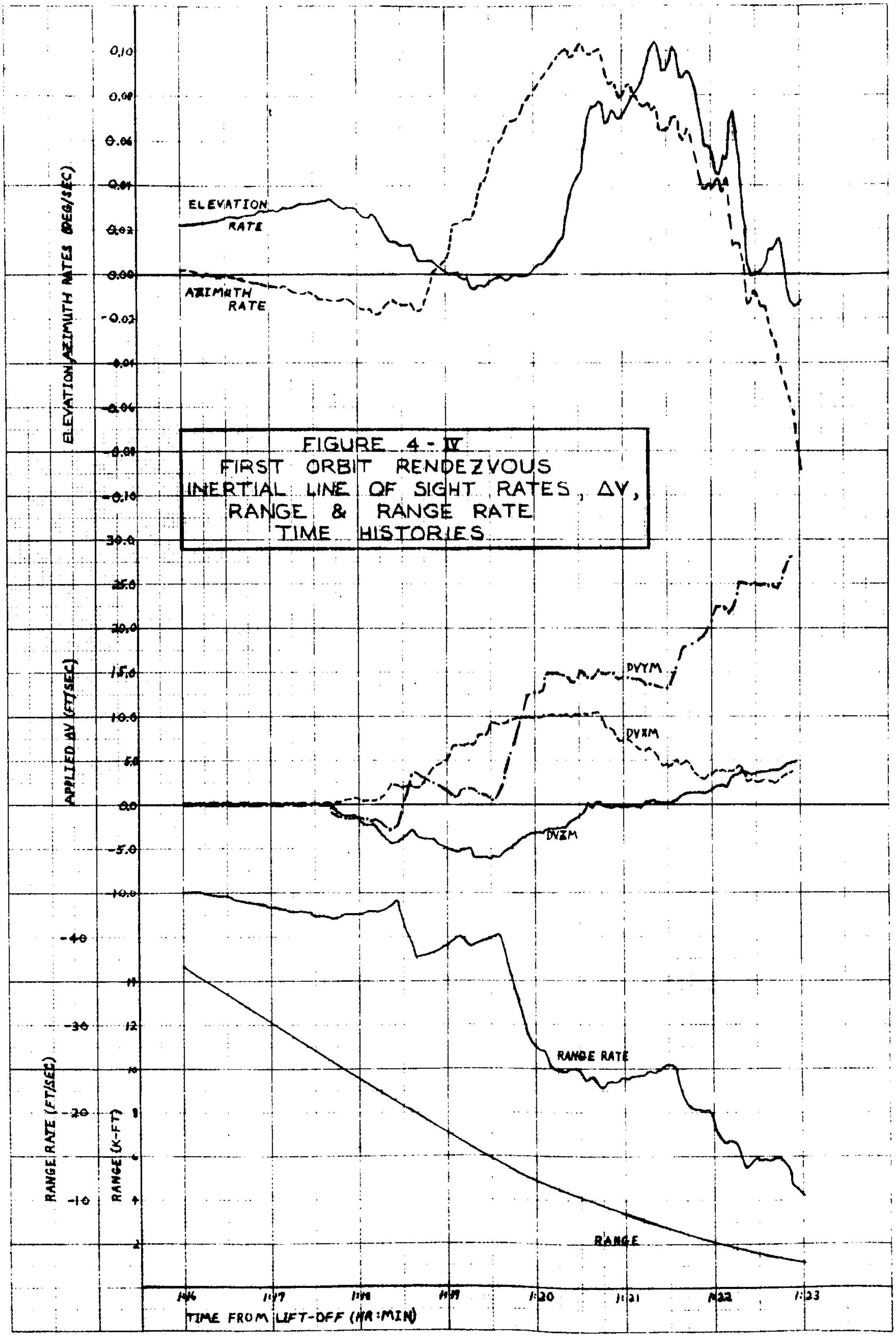


FIGURE 4-IV
FIRST ORBIT RENDEZVOUS
INERTIAL LINE OF SIGHT RATES, ΔV,
RANGE & RANGE RATE
TIME HISTORIES

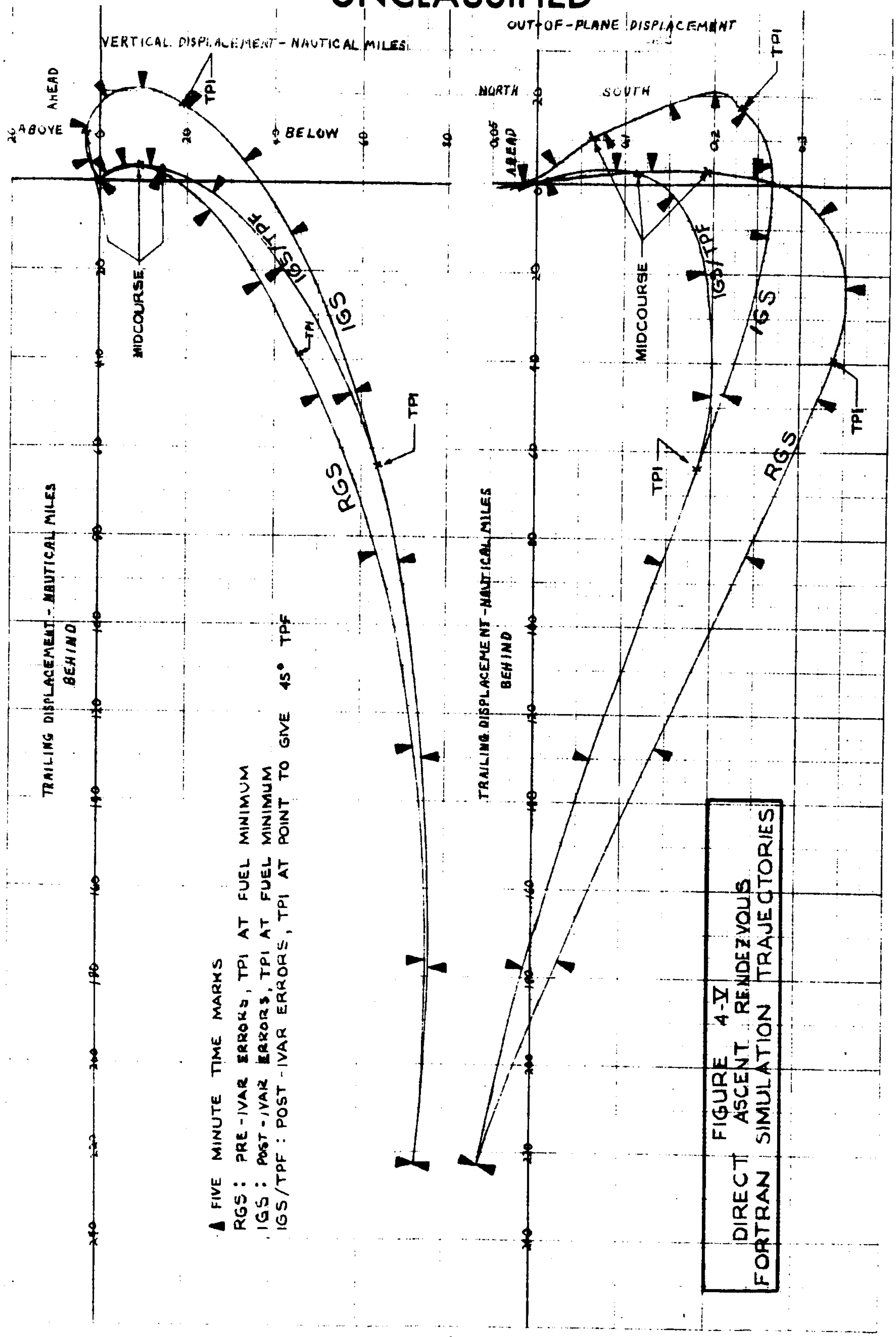


FIGURE 4-V
DIRECT ASCENT RENDEZVOUS
FORTRAN SIMULATION TRAJECTORIES

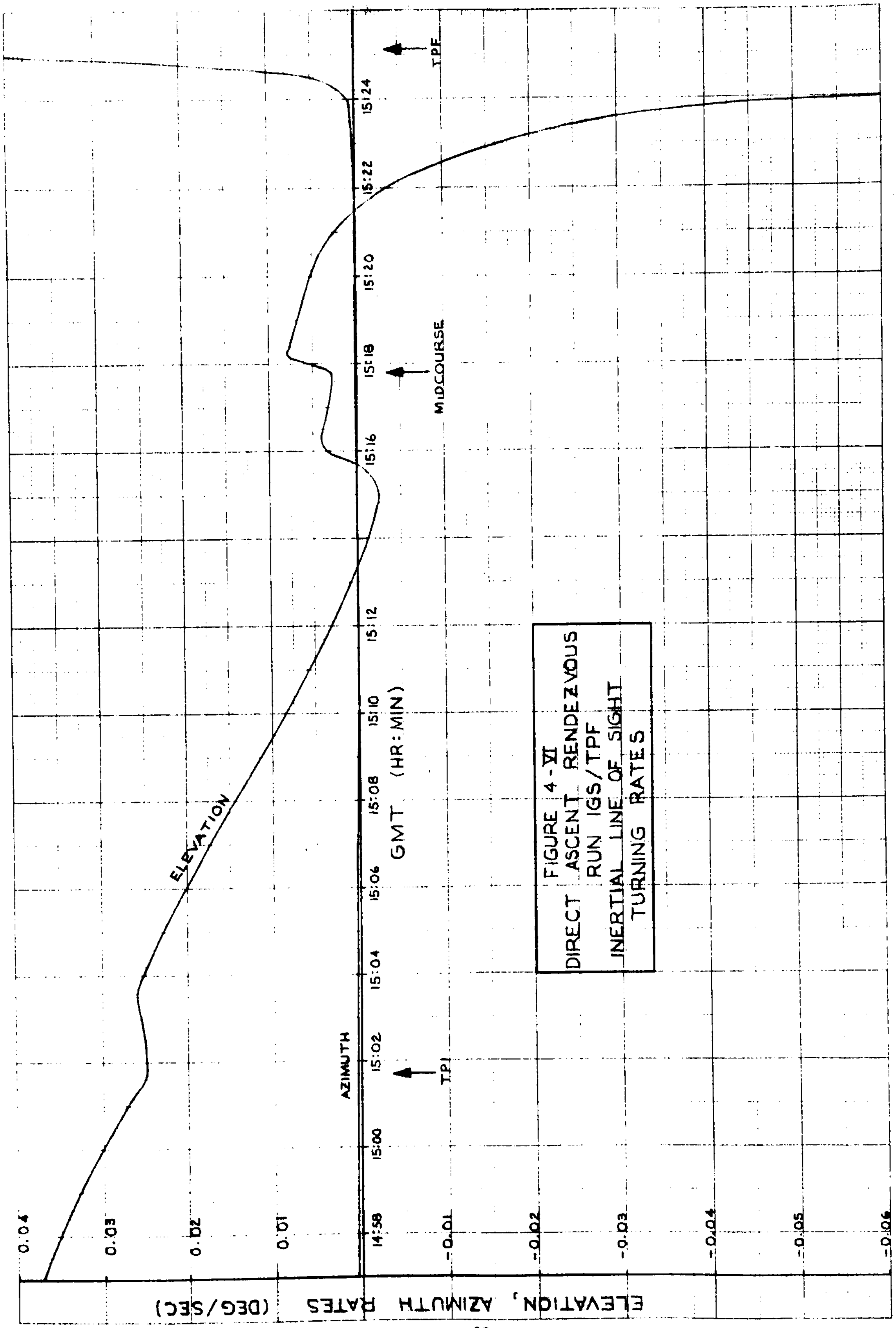


FIGURE 4-VI
DIRECT ASCENT RENDEZVOUS
RUN IGS/TPF
INERTIAL LINE OF SIGHT
TURNING RATES

5.0 REENTRY ANALYSIS

5.1 General Analysis of Data

The following comments pertain to conditions during reentry based on the telemetry data received from the on-board tape:

> Time of retrograde was set at 70 hrs, 41 min, 36 secs. It appears to have occurred at 70 hrs, 41 mins, 36.524 secs., an error of 0.524 secs. This will cause a navigational error of approximately 1.86 nautical miles uprange (opposite to direction of travel), 0.042 n.m. left in cross range and 2.20 n.m. low in altitude.
>
> The accelerometer pulses indicate a retarding ΔV of about 1.624 ft/sec. along the X-axis of the spacecraft body reference which was applied over a period of 30 seconds ending 1.5 minutes before retrograde. At the time of the ΔV application, the spacecraft was in approximate retrograde attitude. The direction of the ΔV was +200.7 degree pitch and 351 degrees in yaw.
>
> It cannot be determined from telemetry data whether compensation for this ΔV was included in the initial conditions. However, if the ΔV was not compensated for in the initial conditions, it imparted an additional error of approximately 0.173 n.m. down range, 0.002 n.m. right in cross range and 0.521 n.m. high in altitude at 80,000 feet true altitude for a total error of 1.69 n.m. down range, 0.040 n.m. left in cross range and 1.68 n.m. or approximately 10,000 feet low in altitude.
>
> Retrograde attitude was maintained at an average of 21.6 degrees to the local horizontal. The accumulated velocities were 304.2 fps aft, 0.89 fps right and 119.1 fps down for a total of 326.721 fps, off nominal by 0.762 fps high. The spacecraft reached 400,000 feet altitude at 1211.5 secs. after retrofire. Nominal time was 1212 secs. At this time the spacecraft was rolled from zero to -45° roll gimbal angle and held around there until the acceleration exceeded the threshhold, at which time the roll altitude began to follow the computer commands. The computer commands were followed down to termination of guidance.

Initial down range error was 99 n.m. and the cross range error was -1.621 n.m. Down range and cross range error were zeroed at 218408 feet altitude, 153 seconds after the acceleration threshhold was reached.

Guidance was terminated 100,000 feet, according to the computer, at about 1747 seconds after retrofire. The closest approach to the target was 1.447 n.m. north. The position coordinates were read out of the computer during flight slightly after this time. They were: 290.02° east and 24.18° north, which is a miss distance of 1.2 n.m. north and 1.2 n.m. east. The position coordinates read out of the computer during the flight were computed at 1797 secs. after retrograde at an altitude of about 73,000 ft. according to the computer.

5.2 Reentry Reconstruction

The reconstruction of the GT-11 Reentry Flight Data was made working from the real time flight data which was recorded on the on-board tape and time tagged and converted to floating point by the McDonnell Corporation.

The reconstruction program uses as inputs the computer cycle times (DTC), sum of the pulses from the accelerometers (SFXP, SFYP, SFZP), and roll gimbal angle (PHIB). Within the accuracy of this input information, which is fed to it by the reconstruction program, the Gemini simulator duplicates each computer cycle taken by the spacecraft computer during reentry.

Tables 5-2 and 5-3 show the results of the reconstruction compared with the flight data at 400,000 ft. altitude and at termination of guidance.

5.2.1 Reconstruction Errors

The following error sources are known to exist in the reconstruction and are held accountable for the differences noted between the reconstruction and the flight data:

1. Uncertainty of the time of initiation of retro fire.

2. Effect of limit cycling of the accelerometers before retro occurs.

3. The effect of the rise and fall times of the retro impulse from the individual rockets is smoothed over in the interpolation of the sum of the accelerometer pulses.

4. Uncertainty of the termination of retro fire.

5. Linear interpolation of the accelerometer pulses to get the number of pulses accumulated during computer cycles which occur between DAS frames.

6. Uncertainty of computer cycle times for computer cycles which occur between DAS frames.

TABLE 5-1
DCS LOAD FOR GT-11 REENTRY

PARAMETER	OCTAL VALUE	DECIMAL VALUE	
XER	226946000	19,785,300.0 ft.	
YER	105324000	9,098,100.0 ft.	
ZER	035203000	1,737,600.0 ft.	
$\dot{X}ER$	660053000	- 1,022,970.0 fps	
$\dot{Y}ER$	233176000	1,987,140.0 fps	
$\dot{Z}ER$	136415000	1,209,930.0 fps	
θ_T	241757000	290.60°	
ϕ_T	015374000	24.16°	
$\Delta\theta_R$	126654000	155.48°	
CK19	150503576	.102179997	fps/pulse
CK20	000003723	.000007460	fps/pulse
CK21	777742247	-.000056600	fps/pulse
CK22	000025262	.000040717	fps/pulse
CK23	000001562	.000003287	fps/pulse
CK24	146001507	.099612500	fps/pulse
CK25	000066046	.000103138	fps/pulse
CK26	630257714	-.101227000	fps/pulse
CK27	777771273	-.000012653	fps/pulse
CK28	021076000	.267517090	pulse/sec
CK29	757024000	-.264999891	pulse/sec
CK30	076267000	.974334716	pulse/sec
ACCT	000400000	1.0	ft/sec^2
KBA		5.79	deg.

TABLE 5-2

Comparison of Telemetry and Reconstructed Data at 400,000 Feet

Parameter	Reconstruction	Telemetry	Difference
TDAS	2,695.979 sec.	2,695.979 sec.	0.000 sec.
RS	21,306,660.000 ft.	21,307,264.000 ft.	604.000 ft.
PHI	28.819 deg.	28.818 deg.	0.001 deg.
THETAE	258.040 deg.	258.056 deg.	0.016 deg.
VE	24,385.186 fps.	24,384.589 fps.	0.596 fps.
GAMMA	-1.395 deg.	-1.395 deg.	0.000 deg.
PSIE	90.705 deg.	90.713 deg.	0.008 deg.
TTDAS	1,214.113 sec.	1,214.378 sec.	0.265 sec.

TABLE 5-3

Comparison of Telemetry and Reconstructed Data at Termination of Guidance

Parameter	Reconstruction	Telemetry	Difference
TDAS	3226.697 secs.	3226.698 secs.	0.001 sec.
RS	21016000 ft.	21015664 ft.	336 ft.
VE	1762.527 fps.	1763.816 fps.	1.289 fps
GAMMA	-23.873 deg.	-24.074 deg.	0.201 deg.
PHI	24.198 deg.	24.1944 deg.	0.004 deg.
THETAE	289.899 deg.	289.9097 deg.	0.010 deg.
PSIE	103.865 deg.	103.866 deg.	0.001 deg.
BC*	24.492 deg.	17.975 deg.	6.517 deg.
RP*	5.75 n.m.	5.687 n.m.	0.07 n.m.
D*	4.676 n.m.	4.6748 n.m.	0.002 n.m.
RC*	-0.97 n.m.	-0.912 n.m.	0.06 n.m.
RT	6.36 n.m.	5.667 n.m.	0.70 n.m.
RO*	0.53 n.m.	-0.09 n.m.	0.62 n.m.
TTDAS	1744.831 secs.	1745.101 secs.	0.27 sec.

* These quantities were computed in the previous comp cycle.

6.0 TELEMETRY TAPE PROCESSING

A total of ten tapes of on-board computer telemetry words were processed by IBM as part of the GT-11 post-flight activity. Table 6-1 lists both the ten tapes which were received and the processed tapes which were shipped to various organizations.

The general procedure used in processing telemetry tapes is as follows:

1. The input tapes are put through a pre-processing program which reformats the data for use with other programs.

2. The pre-processed tapes are fed to the Data Reduction Compiler (DRC) program which time tags the individual quantities. The Gemini telemetry system takes frames of twenty-one computer words at 2.4 second intervals. Since the computer and the telemetry system run asynchronously, it is generally true that the telemetry frames are taken when the computer is part way through a computation cycle. Therefore, some of the quantities in the frame have been updated during the cycle in which the frame is taken and others remain at the values computed during the previous computation cycle. Time tagging associates the time of the proper computation cycle with each quantity in the frame.

3. The output of the DRC program is used as input to the Time Align program. In general, each of the quantities in a telemetry frame is computed at a different time. The Time Align program adjusts the various quantities to the values they would have had if they had all been computed at the same time. For Ascent and Reentry data, the quantities are adjusted to the times the accelerometer are read. Catch-Up and Rendezvous quantities are adjusted to radar interrogation times.

4. The output of the Time Align program is visually inspected to detect records which, due to partial telemetry dropouts, noise or other similar reasons, contain data which are obviously incorrect.

These records are edited from the tapes by further passes through the Time Align program.

5. The final edited data tapes are then copied, and the tape copies and/or tape listings are shipped to the proper organizations.

The first eight tapes listed in Table 6-1 were sent from NASA and were put through the entire process outlined above. During this operation it was discovered that the time periods covered by the first two tapes overlapped. Extensive editing was required to eliminate the duplicate data.

The Ascent portion of the Ascent/Rev 1 input tape was combined with the Ascent tape in one output tape. After this output tape had been shipped it was discovered that a program error had caused some of the data to be left off the tape. The error was corrected and a new output tape was shipped.

Six input tapes containing data from the Catch-Up and Rendezvous modes were processed with no problems. The information was combined in four output tapes for distribution.

The Reentry tape was sent from the McDonnell Corporation. Since the data on this tape had already been time tagged, the pre-processing and DRC passes were not necessary. However, when the tape was fed through the Time Align program, the output was meaningless. When investigation revealed that there was nothing wrong with the Time Align program and that the input tape contained nothing but zeroes, a new tape was obtained. This tape was processed with no trouble.

FIGURE 6-1

TELEMETRY TAPE PROCESSING SUMMARY

Input Tapes	Date Received	Output Tapes	Date Shipped	Recipients	Comments
ASCENT	9/16/66	Merge of ASCENT and Ascent portion of ASC/REV 1 (3 files)	9/23/66	NASA, TRW Systems, Martin-Marietta, Aerospace, McDonnell*	IBM informed data missing from tape 9/28/66
		Same as Above	9/28/66	NASA, TRW Systems, Martin-Marietta, Aerospace	Corrected tape
ASC/REV 1 REV 2	9/16/66 9/16/66	REV 1/2 (8 files)	9/28/66	NASA, TRW Systems, McDonnell*	
REV 4	9/20/66	REV 3/4 (4 files)	9/29/66	Same as above	
REV 27 REV 28/29	9/20/66 9/20/66	REV 26/27/28/29 (3 files)	10/5/66	Same as above	
REV 41/42 REV 42/43	9/20/66 9/20/66	REV 41/42/43 (8 files)	10/5/66	Same as above	
REENTRY	9/21/66				Bad tape - contained all zeroes
REENTRY	9/28/66	REENTRY	9/30/66	Same as above	

*McDonnell Corporation sent tape listings only. Tapes and listings sent to all others.